様　式　C－19、F－19－1、Z－19　(共通)

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研究課題名（和文）Simultaneous measurement of liquid film thickness and temperature by fluorescent anisotropy

研究課題名（英文）Simultaneous measurement of liquid film thickness and temperature by fluorescent anisotropy

研究代表者

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研究成果の概要（和文）：FAには、Ivv、Ivh、Ihv、およびIhhの4つのコンポーネントがあることがわかっています。これらの中で、Ivvは温度に最大に依存し、Ihhは温度に最小に依存します。 Ivvコンポーネントを使用して、温度と液膜厚さを同時に調べることができます。液膜の厚さが増加するにつれて、Ivv成分は直線的に増加し、液膜温度が上昇するにつれて、Ivv成分は直線的に増加することが見出された。つまり、簡単に言うと、Ivv ＝ｆ（h、T）です。ここで、hは液膜の厚さ、Tは液膜の厚さです。

研究成果の学術的意義や社会的意義
Liquid films are defined as a very thin layer of liquid flowing on a solid surface or sandwiched between two solid surfaces.

研究成果の概要（英文）：It has been found that FA has 4 components, namely, Ivv, Ivh, Ihv, and Ihh. Amongst these, Ivv depends maximum on temperature and Ihh depends least on temperature. Using Ivv component, we can study temperature and liquid film thickness simultaneously. At first microchannels of known thickness were fabricated. These thickness act as liquid film thickness. Then fluorescence anisotropy (FA) were measured using fluorescence microscope. From FA, Ivv component was extracted. This is done using python program. It has been found that, as liquid film thickness increases, Ivv components increases linearly, as the liquid film temperature increaes, Ivv components increases linearly. So in brief, we can say, Ivv=f(h,T), where h is liquid film thickness and T is liquid film thickness.

研究分野：Thermoelectric

キーワード：Fluorescence anisotropy　Liquid film thickness　Liquid film temperature　Fluorescence microscope

１．研究開始当初の背景

Liquid films are defined as a very thin layer of liquid flowing on a solid surface or sandwiched between two solid surfaces. Thin liquid films are widely encountered in various industrial application processes like liquid film of urea-water-solutions (UWS) in automobile exhaust, thin-film evaporation, gas-absorption devices, etc.

２．研究の目的

The characteristic parameters that are associated with a liquid film are film thickness and temperature. These two parameters are coupled together in the heat mass transfer mechanism, like Guo et al. [1] found that the liquid film played a primary role in flow boiling process in micro-channel, and the film thickness affected the thermal load of the fluid greatly, Chauris et al. [2] presented that the film thickness was inversely proportional to the heat transfer process in the evaporation process of the thin film on capillary heated tube, etc. So, it is necessary to understand and study these two parameters. However, in order to optimize the relevant industrial processes, it is necessary to measure the liquid film thickness and temperature, simultaneously. The conventional methods to measure the liquid film temperature are to use thermocouples or thermometers, and to measure the liquid film thickness are optical methods, acoustic methods and electrical methods. But each method has been associated with a limitation or drawback. In this work, we propose a new method, i.e., fluorescence anisotropy, to measure the liquid film thickness and temperature, simultaneously.

３．研究の方法

In the present work, we have used fluorescence anisotropy to simultaneously measure the liquid film thickness and temperature. Fluorescent anisotropy is a value of the polarization degree of the emitted fluorescent normalized by the total fluorescent intensity (Fig. 1).

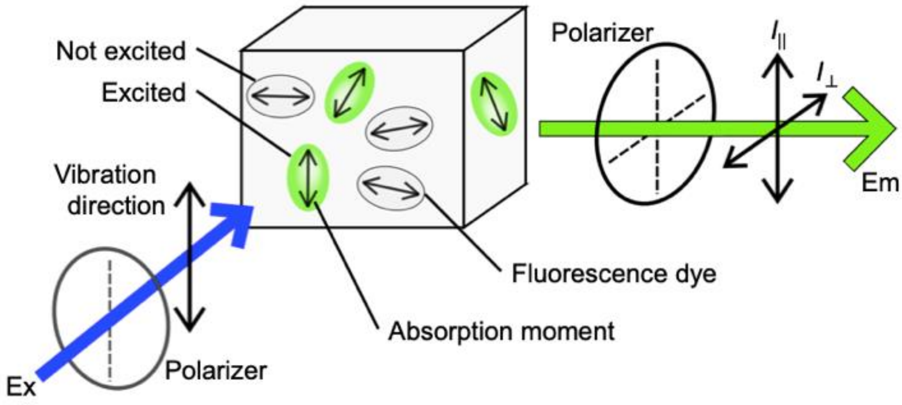

Figure 1: Schematic of fluorescent anisotropy. Fluorescence dye which has parallel absorption moment to incident light is selectively excited.

Mathematically, fluorescence anisotropy is given by the combination of Perrin's and Stokes-Einstein Equation. So, fluorescence anisotropy is:

$$r = \frac{r_0}{1+\frac{\tau k_B T}{V\eta}} \qquad (1)$$

where, r_0 is limiting anisotropy, τ is fluorescent lifetime, k_B is Boltzmann constant, T is solution temperature, V is molecular volume, and η is solution viscosity.

Another way to define fluorescence anisotropy mathematically is shown in Eq. (2).

$$r = \frac{I_{\parallel}-I_{\perp}}{I_{\parallel}+GI_{\perp}} = \frac{I_{VV}-I_{VH}}{I_{VV}+GI_{VH}},\ where,\ G = \frac{I_{HV}}{I_{HH}} \qquad (2)$$

Here the first subscript refers to excitation direction and the second subscript refers to the emission direction.

４．研究成果

At first, it has been found that as the temperature of the solution increases, fluorescence anisotropy increases, which is due to the Eq. (1), which relates that fluorescence anisotropy is inverse of solution temperature. This is shown in Fig. 2. The dashed line in Fig. 2, is the linear fitted line.

Since fluorescence anisotropy decreases with temperature, then it means I_{VV}, I_{VH}, I_{HV}, and I_{HH} also decrease with temperature, because fluorescence anisotropy contains 4 components, I_{VV}, I_{VH}, I_{HV}, and I_{HH}. It has also been found that amongst these 4 components, I_{VV} depends maximum on temperature while I_{HH} depends the least. This is shown in Fig. 3. The reason for this dependence is that the incoming light is itself is elliptically polarized in the y-direction or vertical component. So, for further experiments, I_{VV} component has been used only.

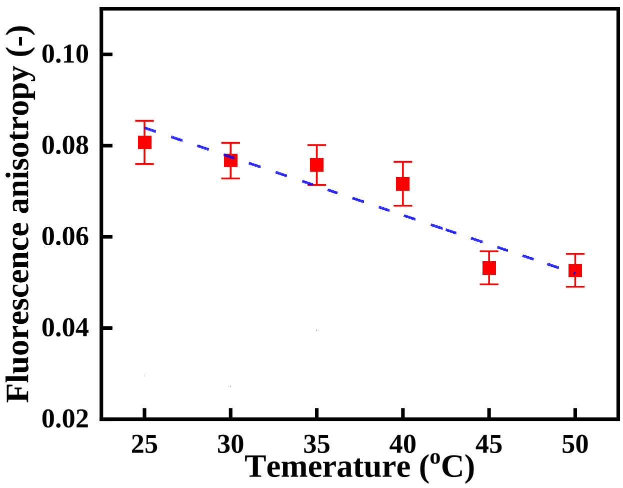

Figure 2: Fluorescence anisotropy as a function of solution temperature.

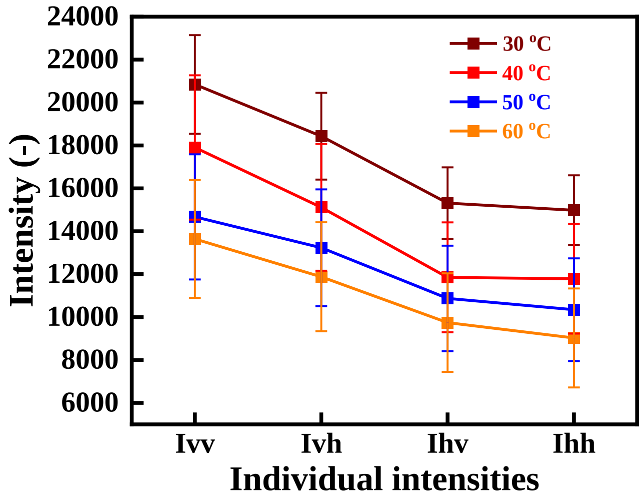

Figure. 3: Fluorescence intensities various components as a function of increasing solution temperature.

Three different microchannels of height ~ 21, 29, and 37 μm were fabricated using soft-lithography. These different height microchannels act as different liquid film thickness in the present work. It is then found that as the liquid film thickness increases, I_{VV} increases linearly. Also, as shown in Fig. 4, as temperature increases, I_{VV} component increases linearly. These two phenomena are combined and shown in Fig. 4, where T_{Ref} is any temperature, at which we want to measure. So, we can conclude our work by saying that

$$I_{VV} = f(T, h) \qquad (3)$$

where, T is the temperature of liquid film and h is the height of liquid film.

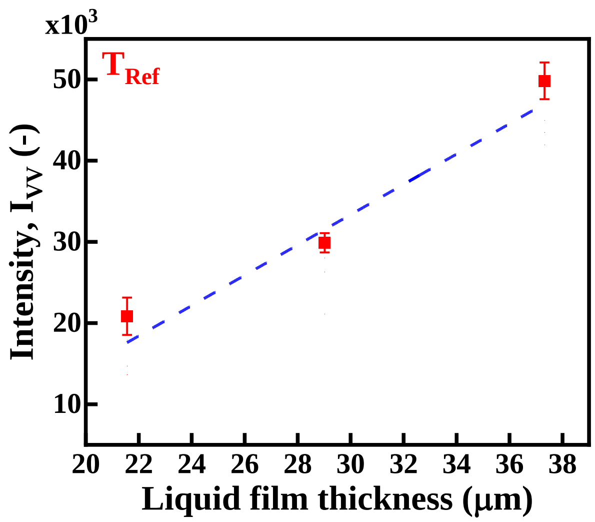

Figure 4: I_{VV} as a function of liquid film thickness and temperature.

Journals:

1. “Fluorescence Anisotropy Studies on BODIPY (Pyrromethene 546) Dyes as a Novel Thermal Probe”, **Puneet Jain** and Masahiro Motosuke, *J. Fluor.* (2022) DOI: 10.1007/s10895-021-02868-0).
2. “Fluorescence Anisotropy as a Temperature-Sensing Molecular Probe Using Fluorescein” **Puneet Jain**, Takuya Aida, and Masahiro Motosuke, *Micromachines*., 12(9) 1109 (2021).
3. “Temperature Sensitivity of BODIPY Dye (Pyrromethene 597) over Different Linear Organic Solvents”, **Puneet Jain** and Masahiro Motosuke, submitted in *Jpn. J. Appl. Phys.*

Conferences:

1. “Fluorescence Anisotropy Studies on BODIPY (Pyrromethene 546) Dyes as a Novel Thermal Probe” **Puneet Jain**, Yoshihasu Ichikawa and Masahiro Motosuke, The 2nd Asian Conference on Thermal Sciences, October 3-7’ 2021, (online).
2. “Temperature sensitivity of BODIPY dye (pyrromethene 597) over various organic solvent” **Puneet Jain**, Ryosuke Yamaguchi, Yoshihasu Ichikawa and Masahiro Motosuke, The 12th Symposium on Micro-Nano Science and Technology, November 9-11’ 2021 (online).
3. 蛍光異方性を用いた液体温度測定における粘性 率の影響, 山口 玲輔, 元祐 昌廣, **JAIN Puneet**, 市川 賀康, 第 42 回日本熱物性シンポジウム, October 25-27’2021, (online).

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1. C. Guo, J. Tao, Y. Jiang, et al., Measurement and theoretical analysis of transient liquid film during micro-channel flow boiling, Int. J. Multiph. Flow 130 (2020) 103365.
2. N. Chauris, V. Ayel, Y. Bertin, et al., Evaporation of a liquid film deposited on a capillary heated tube: Experimental analysis by infrared thermography of its thermal footprint, Int. J. Heat Mass Transf. 86 (2015) 492–507.

５．主な発表論文等

〔雑誌論文〕　計3件（うち査読付論文　0件／うち国際共著　0件／うちオープンアクセス　0件）

１．著者名 Jain Puneet、Motosuke Masahiro	４．巻 61
２．論文標題 Temperature sensitivity of BODIPY dye (pyrromethene 597) over different linear organic solvents	５．発行年 2022年
３．雑誌名 Japanese Journal of Applied Physics	６．最初と最後の頁 056504～056504
掲載論文のDOI（デジタルオブジェクト識別子） 10.35848/1347-4065/ac5fc9	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 Jain Puneet、Motosuke Masahiro	４．巻 32
２．論文標題 Fluorescence Anisotropy Studies on Bodipy (Pyrromethene 546) Dye as a Novel Thermal Probe	５．発行年 2022年
３．雑誌名 Journal of Fluorescence	６．最初と最後の頁 737～743
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/s10895-021-02868-0	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 Jain Puneet、Aida Takuya、Motosuke Masahiro	４．巻 12
２．論文標題 Fluorescence Anisotropy as a Temperature-Sensing Molecular Probe Using Fluorescein	５．発行年 2021年
３．雑誌名 Micromachines	６．最初と最後の頁 1109～1109
掲載論文のDOI（デジタルオブジェクト識別子） 10.3390/mi12091109	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

〔学会発表〕　計3件（うち招待講演　0件／うち国際学会　0件）

１．発表者名 Puneet Jain, Yoshihasu Ichikawa and Masahiro Motosuke
２．発表標題 Fluorescence Anisotropy Studies on BODIPY (Pyrromethene 546) Dyes as a Novel Thermal Probe
３．学会等名 The 2nd Asian Conference on Thermal Sciences
４．発表年 2021年

1．発表者名 Puneet Jain, Ryosuke Yamaguchi, Yoshihasu Ichikawa and Masahiro Motosuke
2．発表標題 Temperature sensitivity of BODIPY dye (pyrromethene 597) over various organic solvent
3．学会等名 The 12th Symposium on Micro-Nano Science and Technology
4．発表年 2021年

1．発表者名 山口 玲輔，元祐 昌廣，JAIN Puneet，市川 賀康
2．発表標題 蛍光異方性を用いた液体温度測定における粘性 率の影響
3．学会等名 第 42 回日本熱物性シンポジウム
4．発表年 2021年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関